Space Dynamics Laboratory
Utah State University Research Foundation

Far-Infrared Instrumentation: FIRST, CORSAIR, and CLARREO

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Space Dynamics Lab

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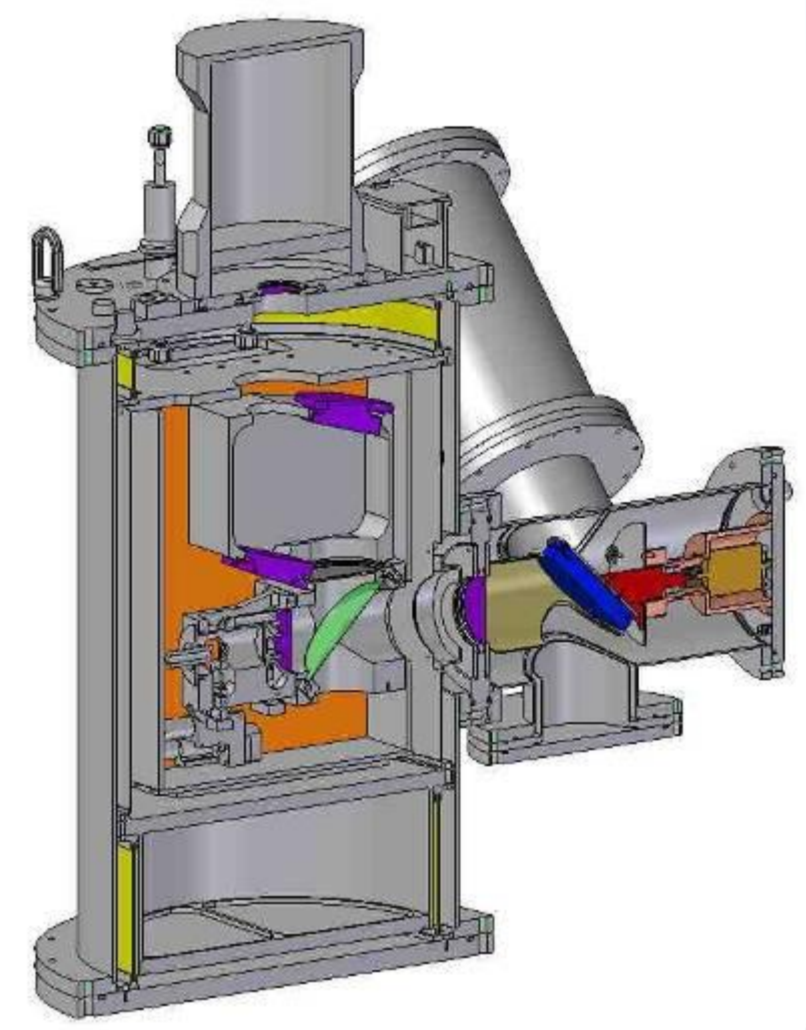
Outline

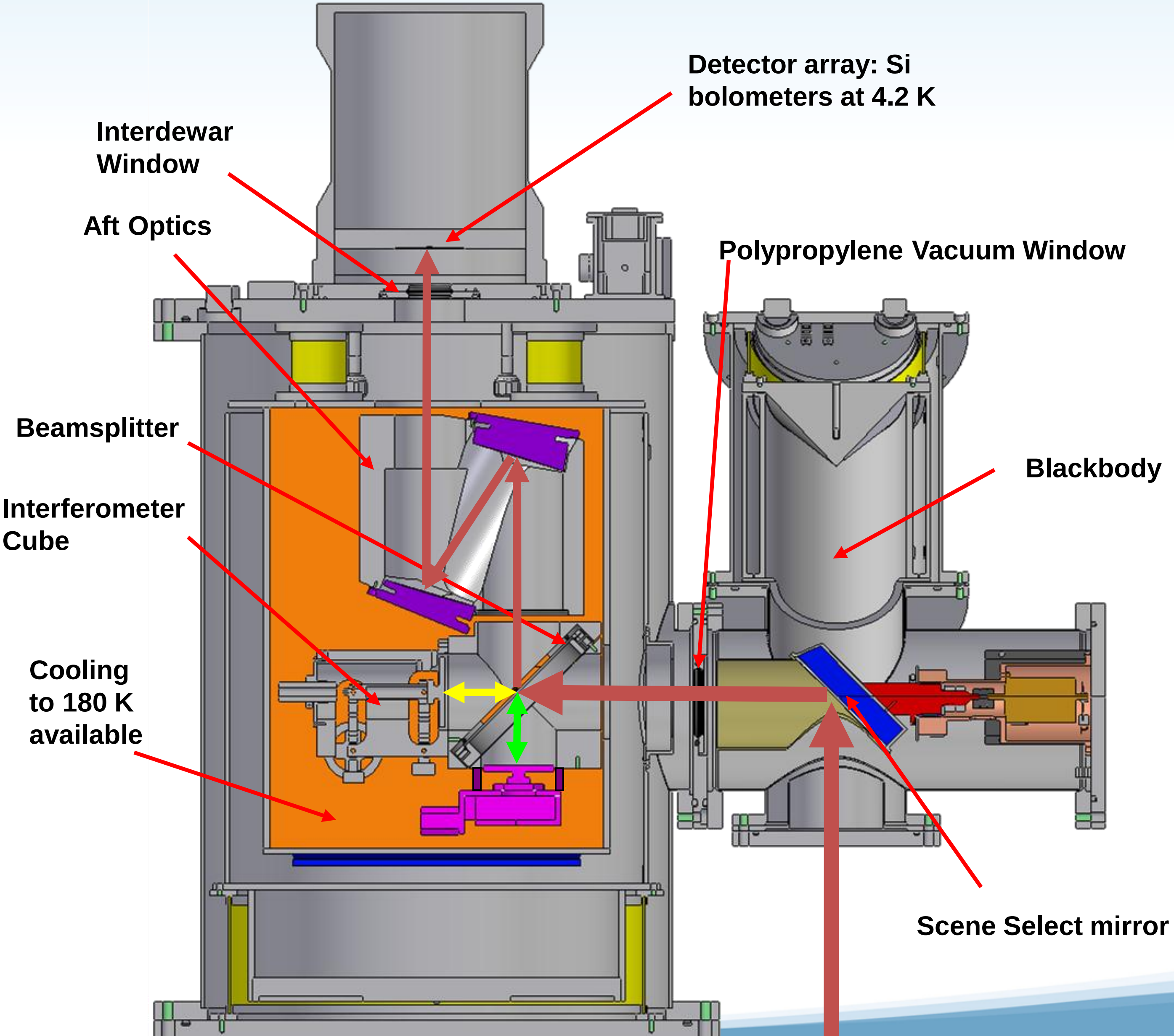
- FIRST
  - Far-IR design
  - Far-IR data
- Far-IR blackbodies
  - LWIRCS and performance
- CLARREO
  - Accuracy and blackbody needs
- CORSAIR Blackbody
  - Design
  - Performance

FIRST (Far-IR Spectroscopy of the Troposphere)

- FIRST is a high-altitude balloon and ground-based instrument to measure atmospheric FAR-IR
- FIRST developed under an instrument incubator program
  - Goal of developing technology needed to attain daily global coverage, from low-earth orbit, of the Earth's far-infrared spectrum
  - Technology to be demonstrated with a prototype instrument in a space-like environment
- Instrument design goals
  - Fourier Transform Spectrometer covering 10 to 100 μm (1000 to 100 cm^{-1})
  - Spectral resolution: 0.6 cm^{-1} (unapodized)
  - NEΔT: 0.2 K (10 to 60 μm); 0.5 K (60 to 100)
  - Accuracy goal: equal to NEΔT
  - On-board blackbodies or blackbody and space view for calibration
  - 7 cm aperture
  - Ability to have 4.4° FOV (100 km from orbit)
  - 0.41° IFOV (10 km from orbit)



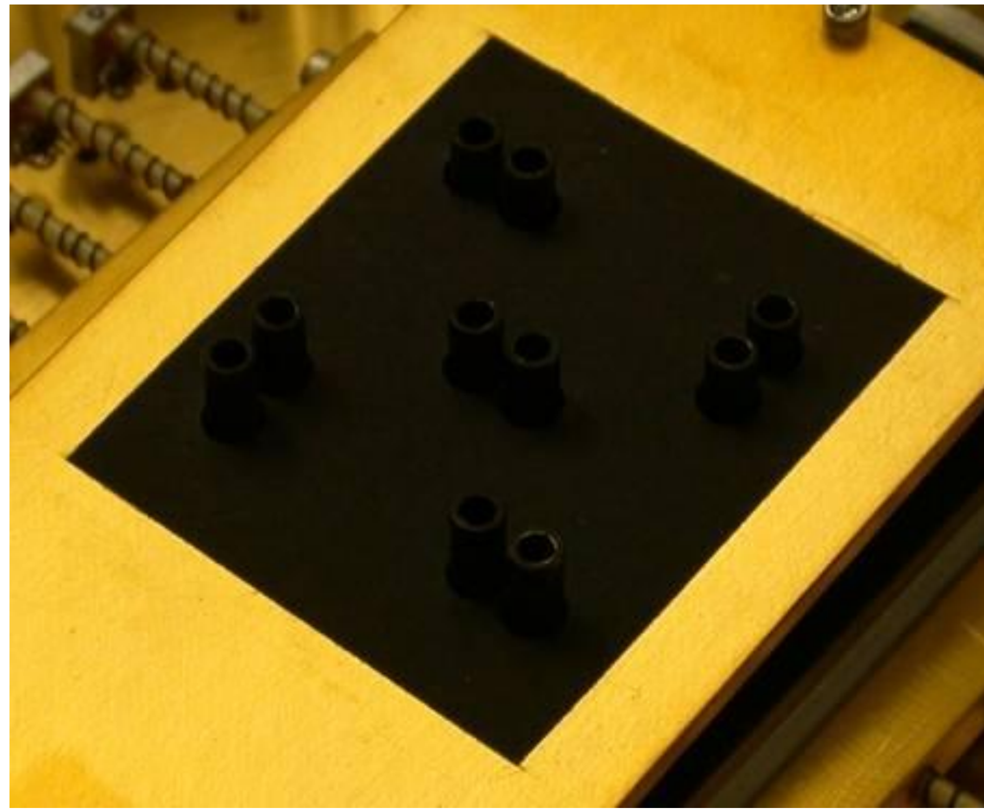
FIRST



- Simple optics
- Three sections
- Three port scene select assembly (SSA)
- SSA rotates
- COTS electronics

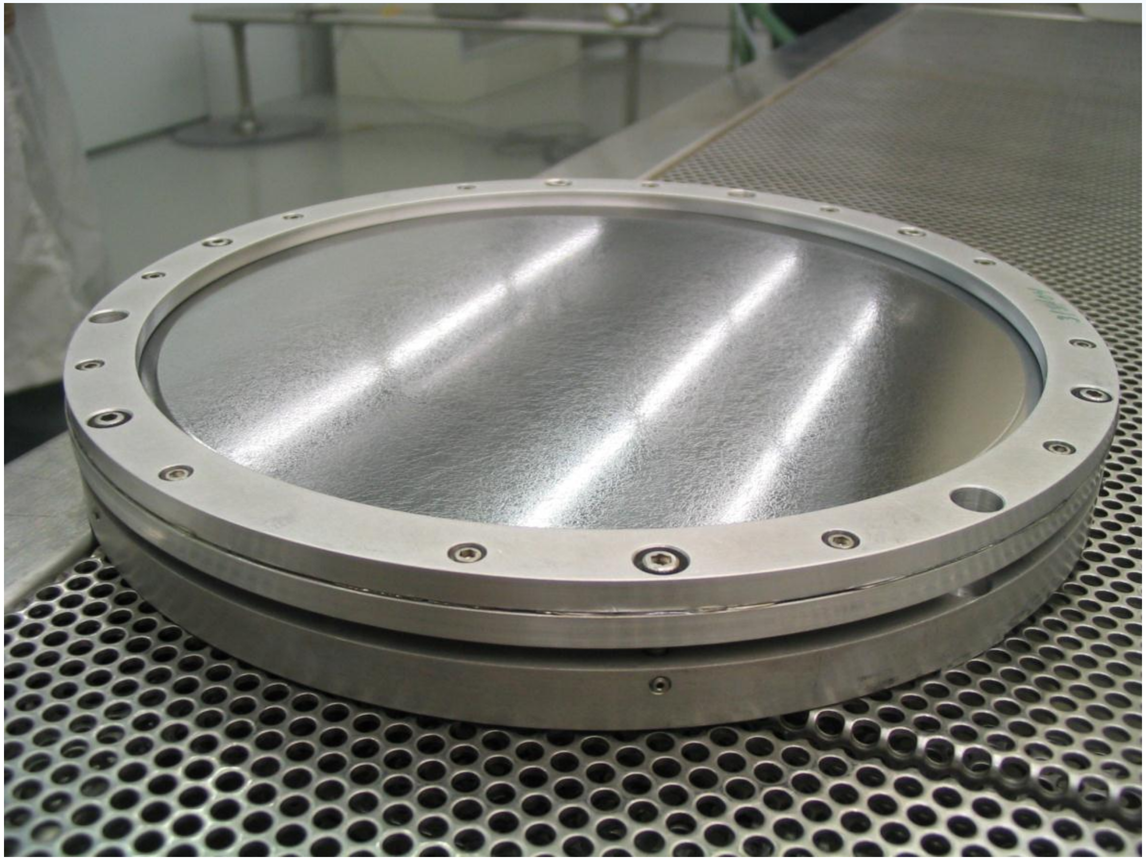
FIRST Detectors

- FIRST uses liquid helium-cooled Si bolometers coupled to Winston cones
  - 3.25 mm (0.125”) cone diameter
  - 0.25 mm detectors
  - Provide more than enough sensitivity, wavelength coverage and electrical bandwidth
- 2 detectors in middle, 2 in each corner to demonstrate large FOV



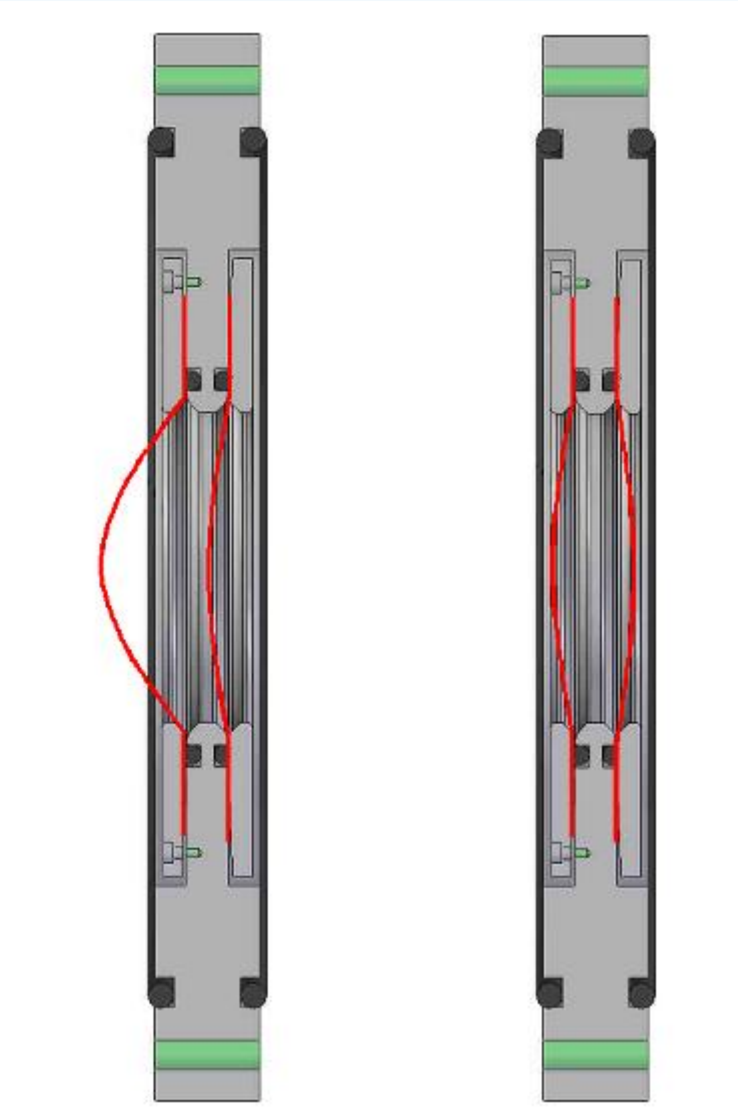
Beamsplitter and DNR

- Beamsplitter is a stretched thin film
  - Ge on Mylar
  - Can become a drumhead
- Need 20 bit dynamic range in interferogram to cover range and desired sensitivity
- Collect two sets of data per detector
  - One with 100x more gain
  - Use low gain data where high gain saturates

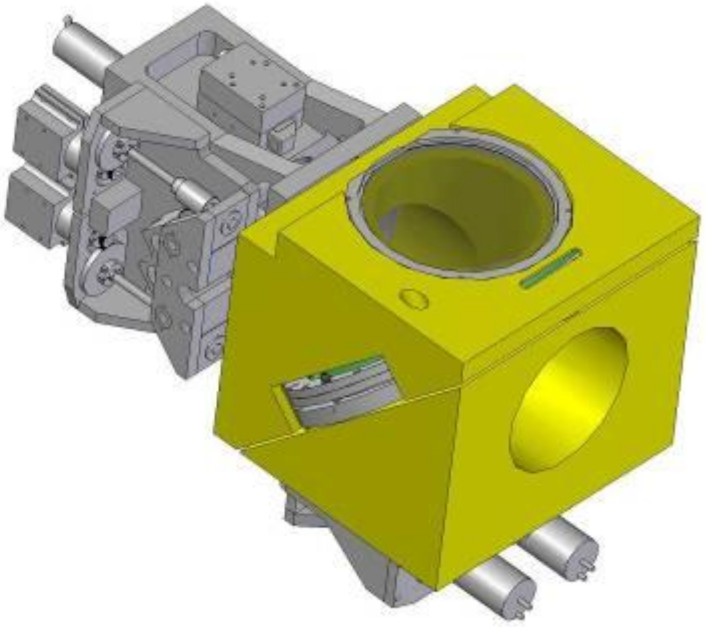


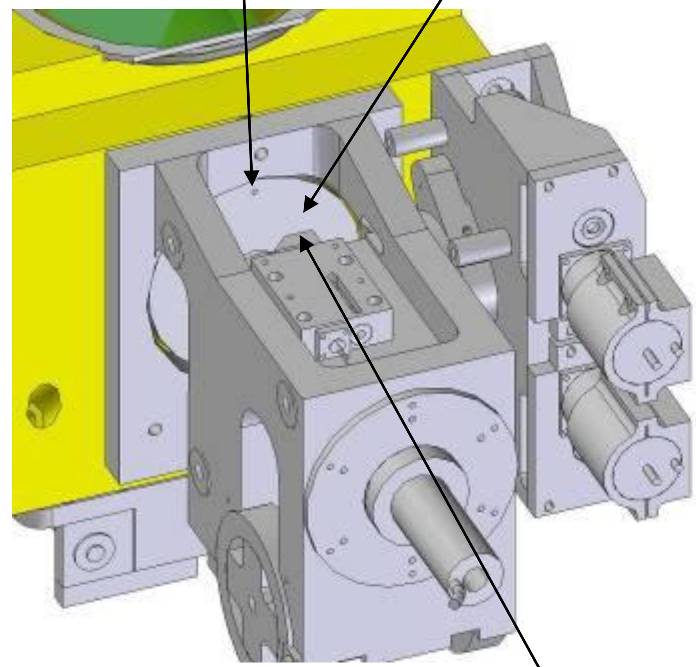
Window

- Window is two polypropylene films (~30 μm)
- Air slowly passes through
- Shape depends on pressure, can change over time



FIRST Interferometer





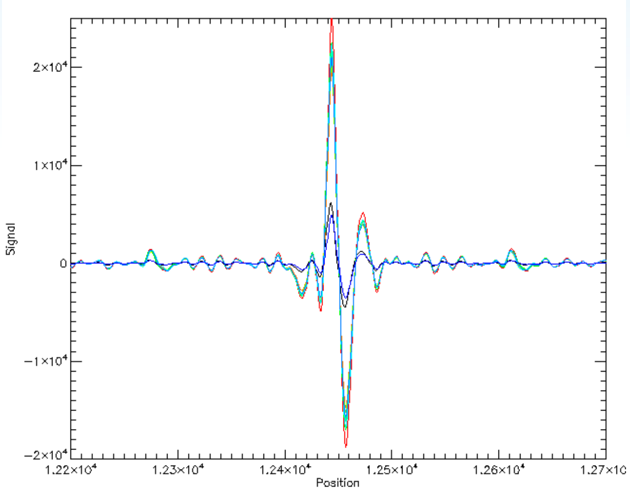
Metrology laser has separate interferometer path

FIRST Operations

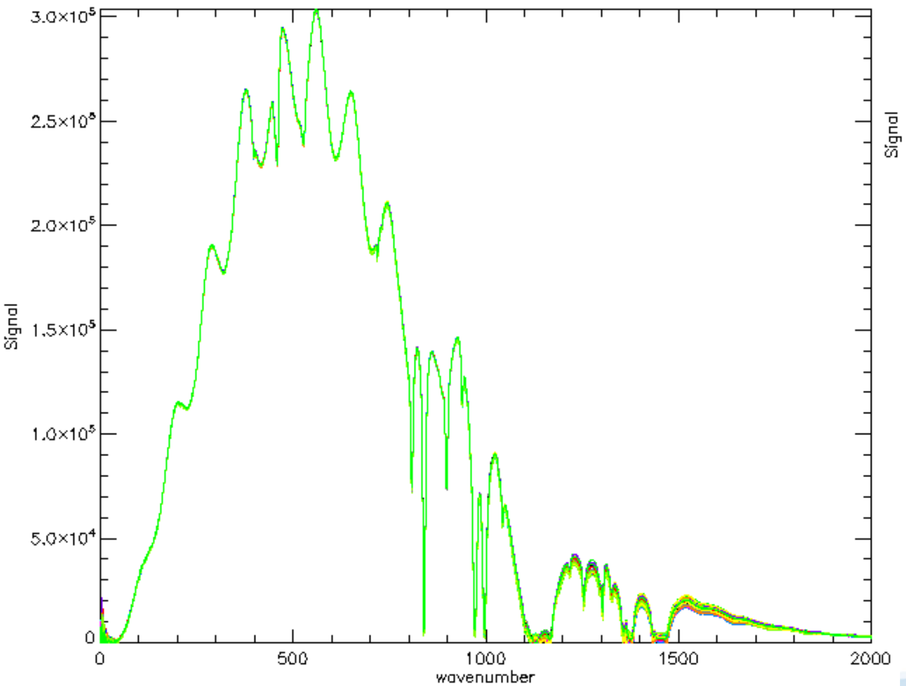
- Flown twice on a high-altitude balloon
  - First flight June 2005
- Several ground operations
  - E.g., Chile in 2009
  - Mauna Loa in 2012
- Ground calibration
  - Feb-March 2005
  - Oct 2011

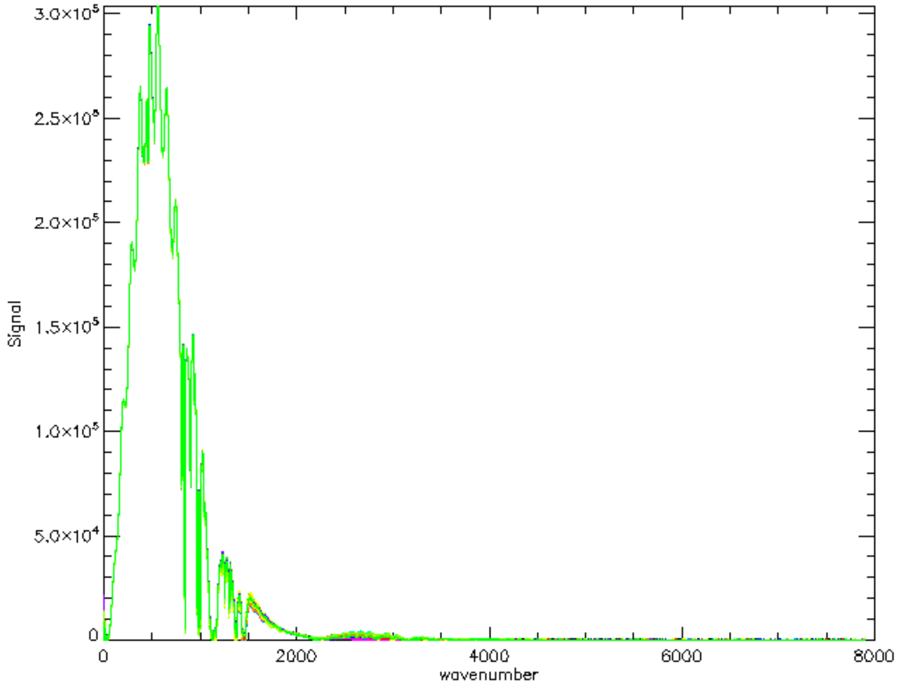
FIRST Data

Centerburst for all detectors, one scan



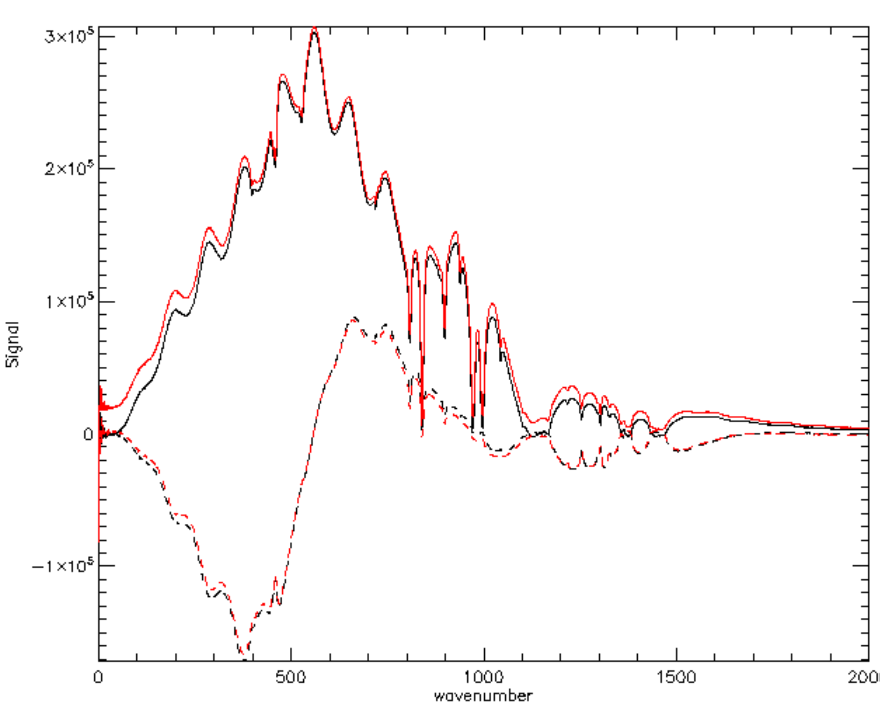
32 spectra of warm blackbody at 324 K, detector 2



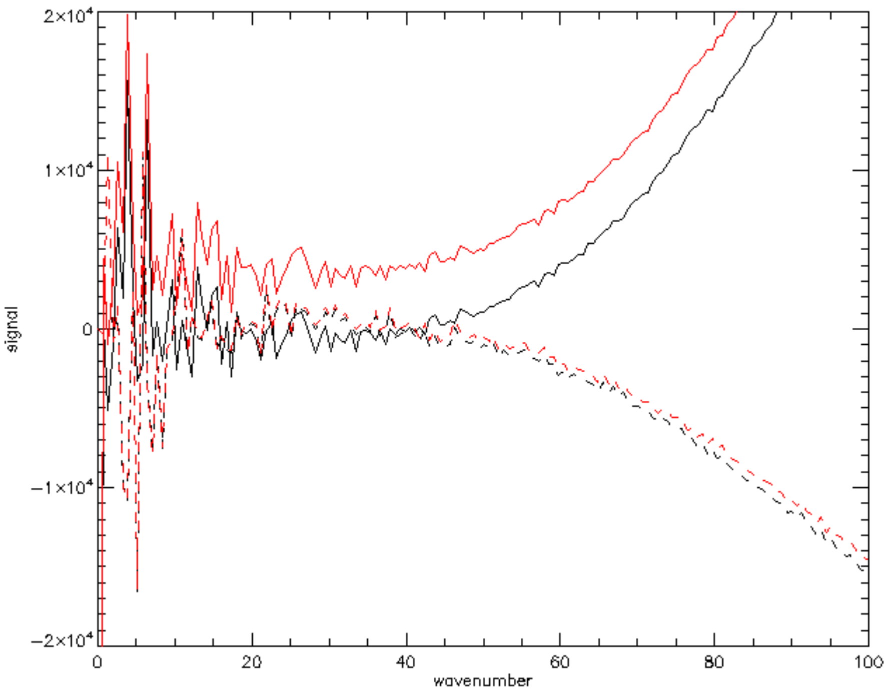


Reponse is wider than 10 to 1000 cm^{-1}

FIRST Linearity



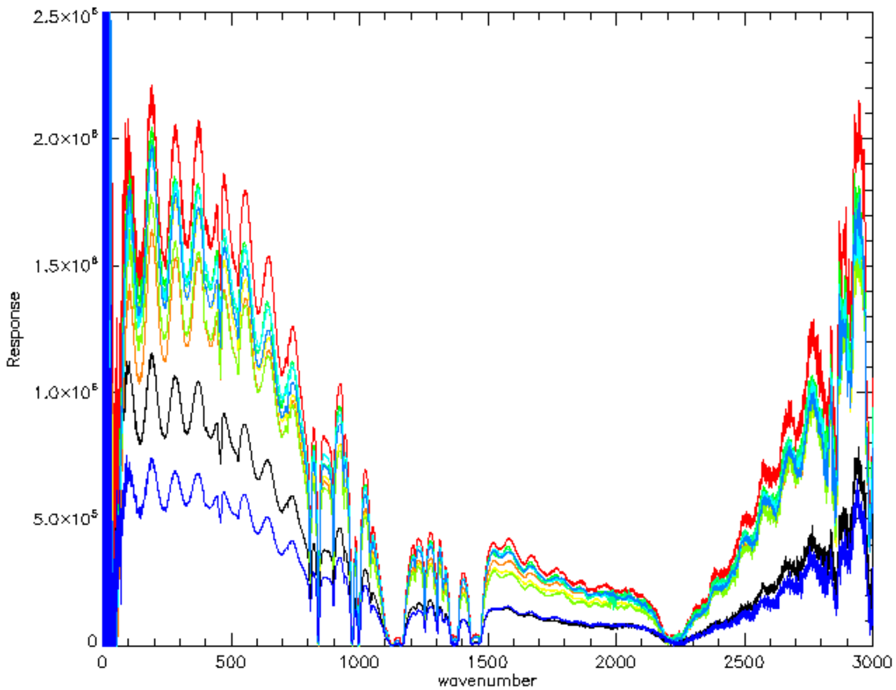
- Single spectrum, no phase correction, dashed line is imaginary part
- Black curve = first spectrum
- Red curve = black with 10% non-linearity added to interferogram



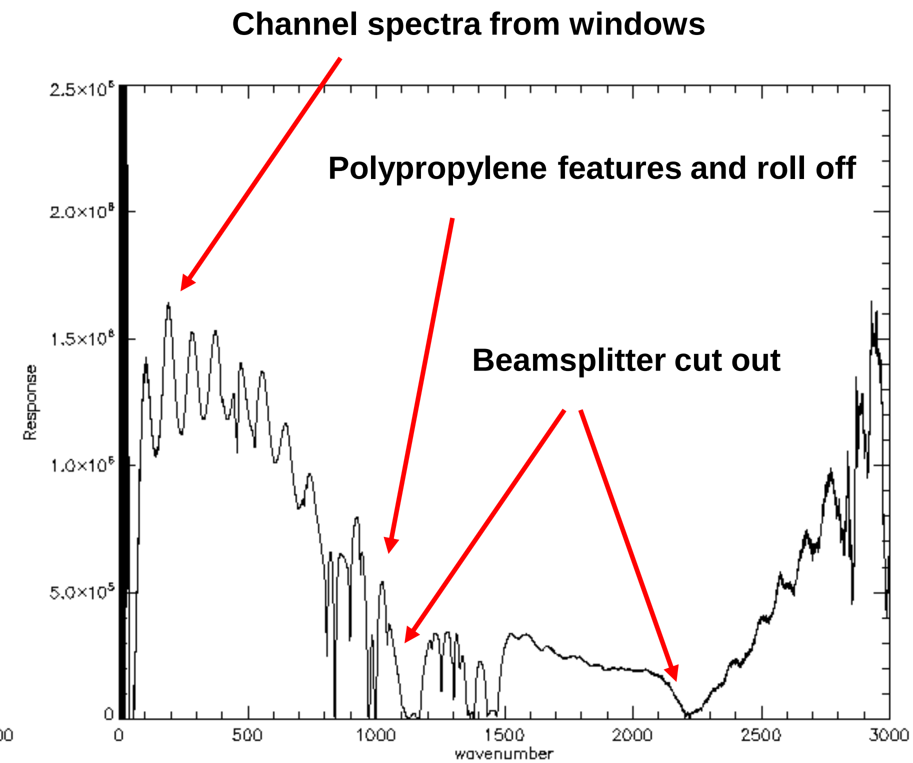
- Red curve now 2% added non-linearity
- FIRST non-linearity well under 1%, probably <0.1%

FIRST Response

Response from warm BB at 324, ambient BB at 295 K



All detectors



Detector 2 only

Some response from 50 to 2200 cm^{-1} (200 to 4.5 μm)

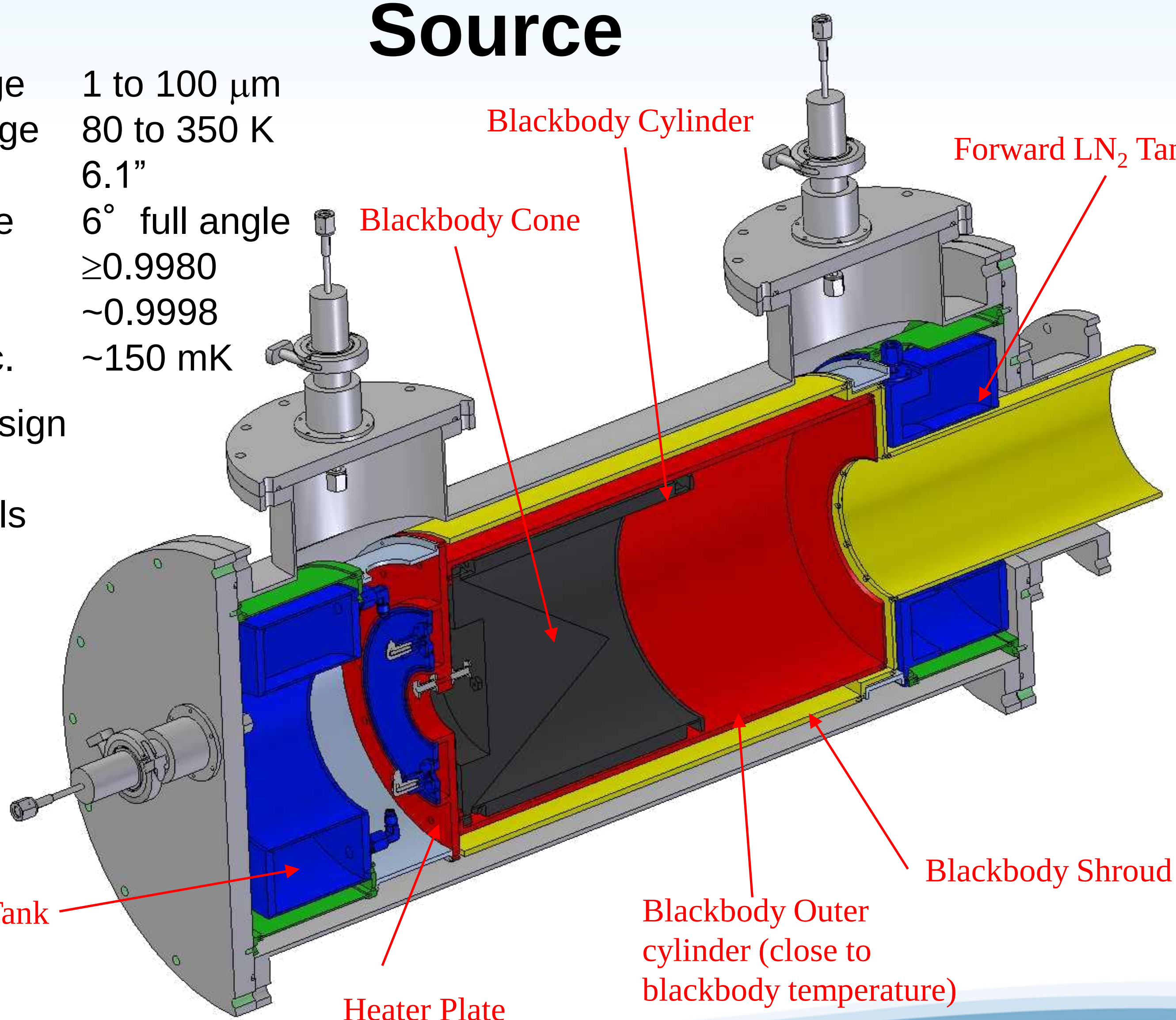
FIRST and Blackbodies

- FIRST has provided successful balloon and ground observations
- Absolute accuracy goal of 0.2 K was attempted, but not met nor expected to be
- To meet goal, high-accuracy blackbodies are required
  - Attached (flight) blackbodies
  - Variable temperature cal. blackbody
  - Space view simulator blackbody

LWIRCS – Long Wave Infrared Calibration Source

- Wavelength range 1 to 100 μm
- Temperature range 80 to 350 K
- Aperture 6.1”
- Beam divergence 6° full angle
- Emissivity 1-100 ≥0.9980
- Emissivity 1-60 ~0.9998
- Temperature unc. ~150 mK

- Specular trap design
- Z302 paint
- Two cooling levels

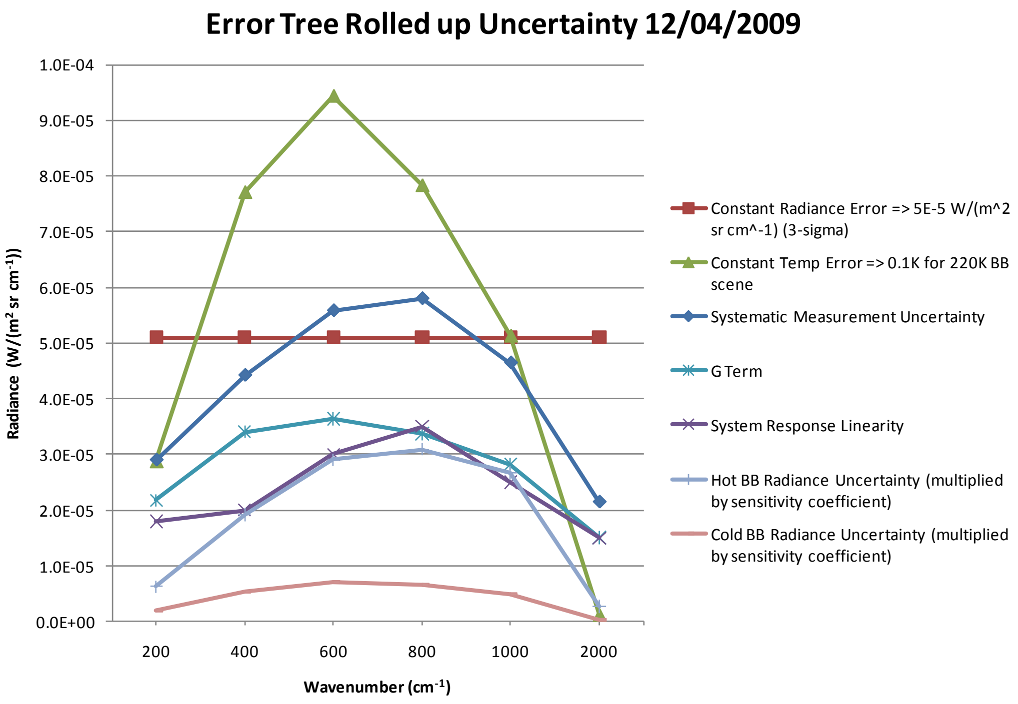


LWIRCS TXR Test

- LWIRCS observed with the NIST TXR (transfer radiometer)
- TXR
  - 5 μm and 10 μm bands
  - Brightness temperature scale tied to NIST water bath blackbody
  - Uncertainty ~90 mK at 5 μm and ~150 mK at 10 μm
- LWIRCS temp vs. TXR scale
  - 5 μm: within 95 mK (max deviation) 210 to 350 K
  - 10 μm: within 186 mK max deviation 180 to 350 K
- LWIRCS 5 μm emissivity measured to be 0.99969±0.00003
  - Heated halo type test
  - About as expected at 5 μm

CLARREO

- CLARREO (Climate Absolute Radiance and Refractivity Observatory) accuracy requirement is:
  - ~0.1 K @ 220 K (3σ) ~200 to 2000 cm^{-1}
  - Maintain accuracy over five years on-orbit
- SDL performed full uncertainty analysis for CLARREO. Blackbody is a significant error source
- SDL has built a prototype (the CORSAIR blackbody) to show ability to meet CLARREO requirements
  - Part of the NASA Langley IIP program CORSAIR



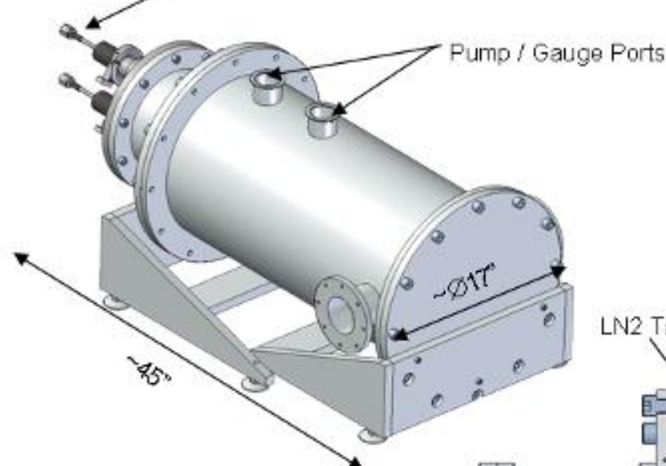
CORSAIR Blackbody Specifications

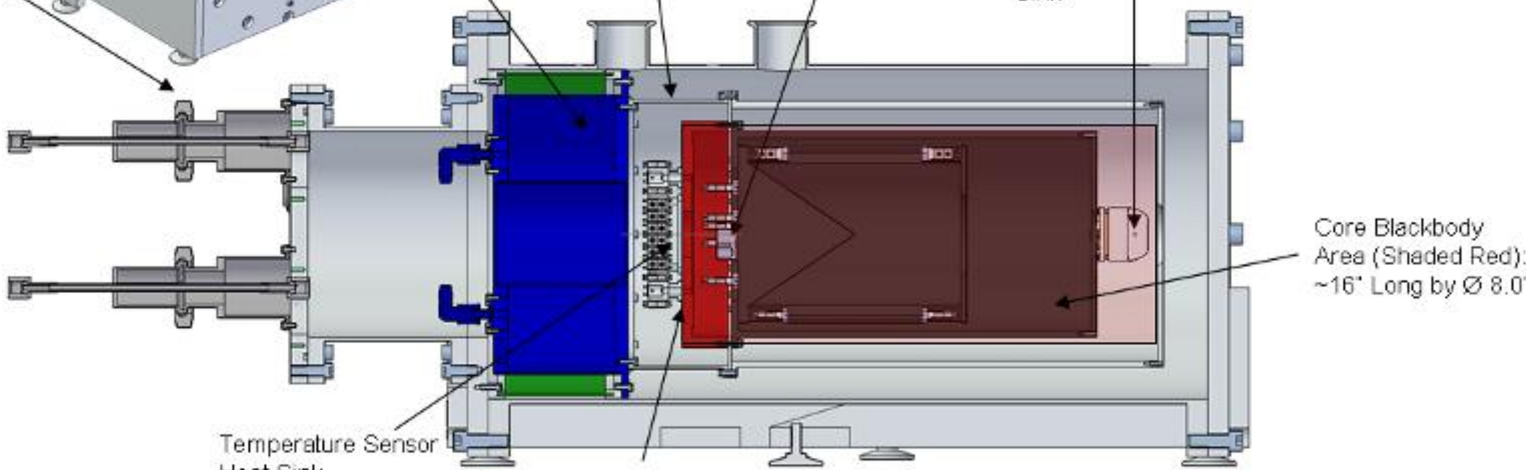
Wavelength range	2 to 50 μm
Controlled temperature range	200 to 350 K
Operating environment	Ambient or inside larger vacuum chamber
Coolant	Liquid nitrogen
Environment temperature	77 K to ambient
Aperture	1.75 inches
Beam divergence	6° full angle
Emissivity	≥0.9999
Temperature uncertainties	30 mK under CLARREO-like conditions

- Blackbody is designed to be a useful ground unit
- Large operating range adds significant complexity

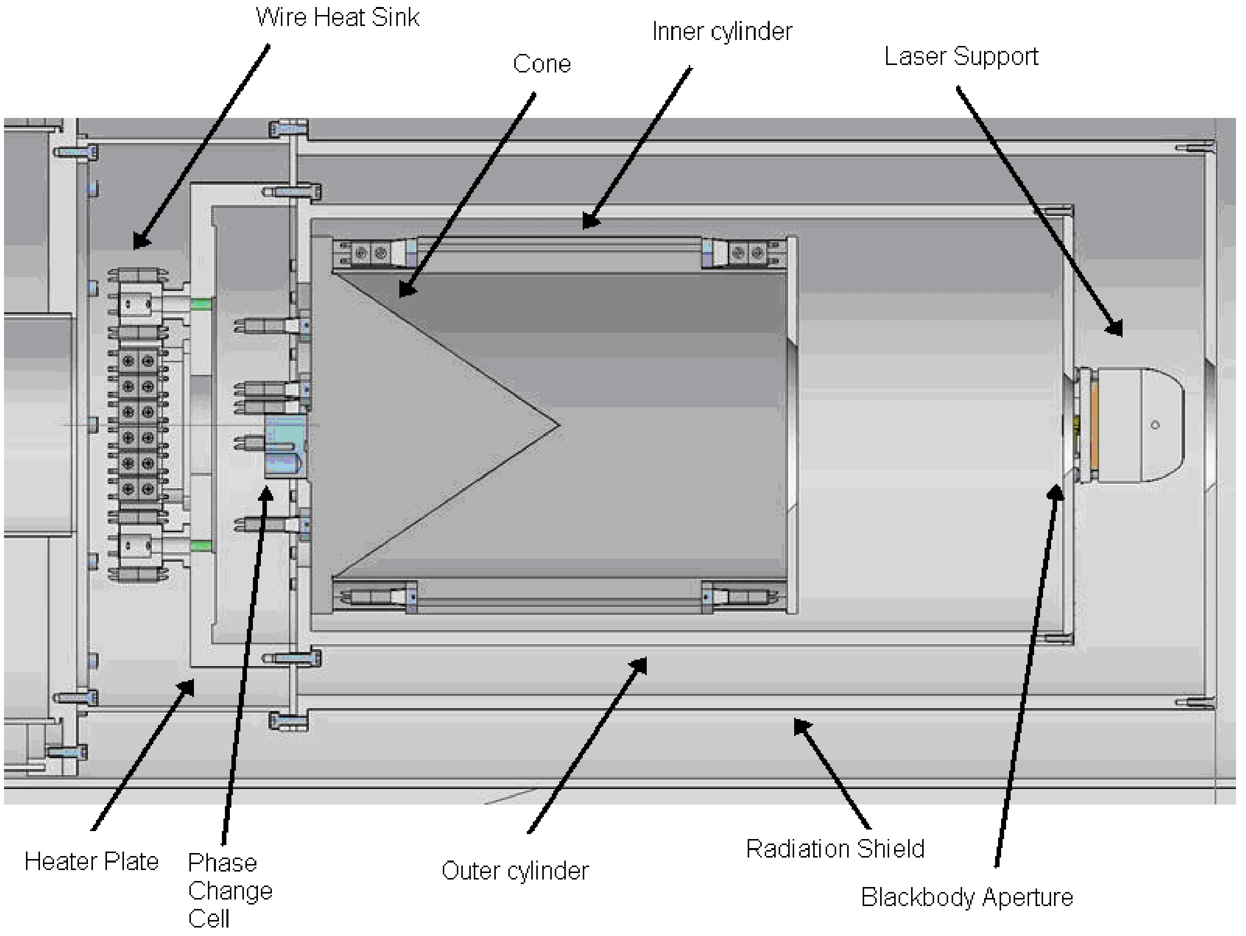
CORSAIR Blackbody Overall Design

Vacuum shell, LN_2 and heated shroud are needed for wide range of environments





CORSAIR Blackbody Cavity Design



- Aluminum, steel, and fiberglass
- Specular trap design, works to long wavelength
- Numerous features keep gradients low

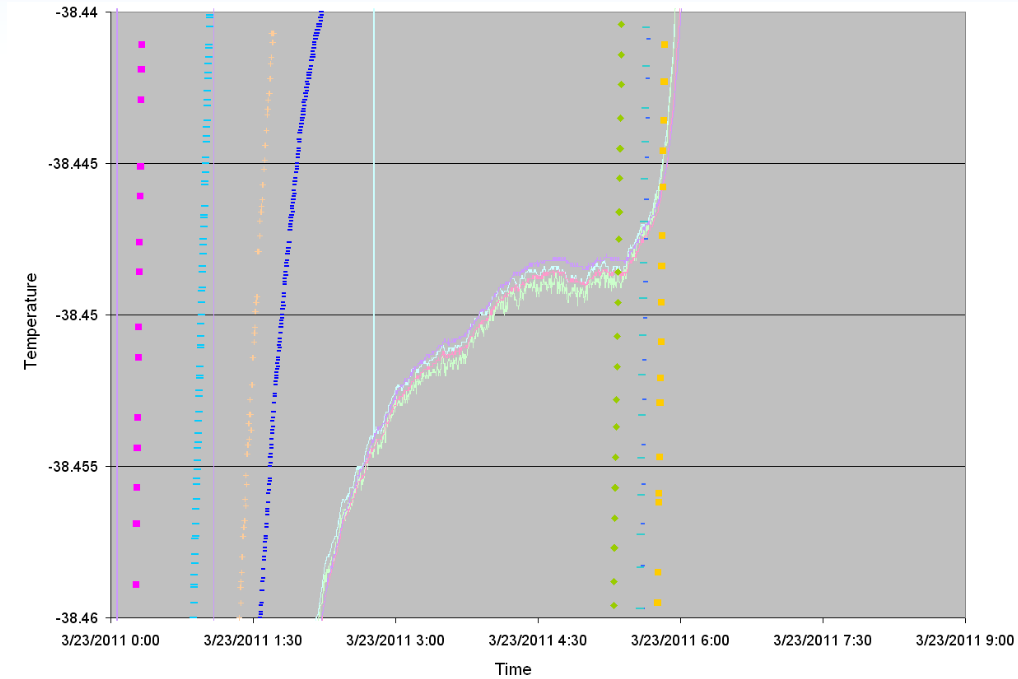
CORSAIR Blackbody Performance

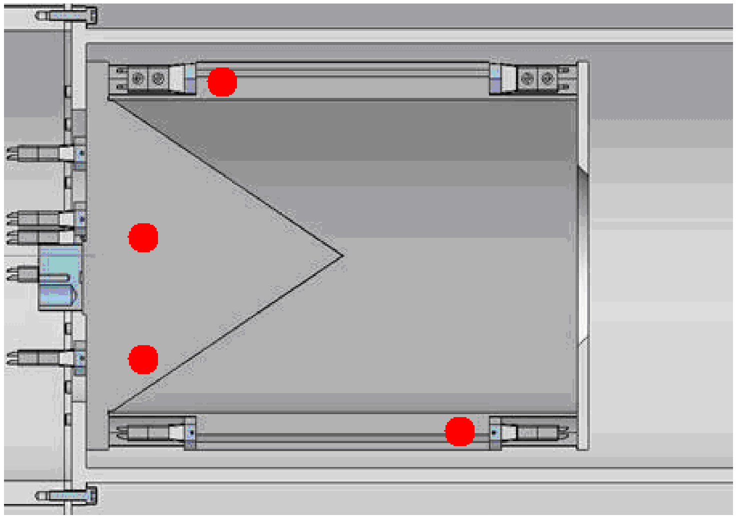
- CORSAIR blackbody has been tested to the extent possible for:
  - Temperature gradients
  - Temperature sensor accuracy
  - Emissivity

- CORSAIR blackbody was designed to allow simple testing of some characteristics

CORSAIR Performance Temp Gradients

- Gradients across surfaces viewed in blackbody introduce error
- Can test for temperature gradients with sufficiently accurate temperature sensors at critical locations in blackbody



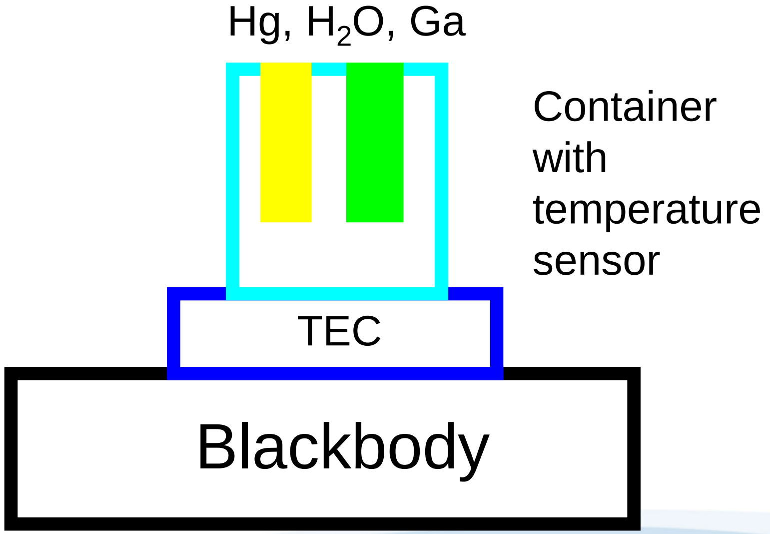


- Plot of sensors on CORSAIR blackbody cylinder and cone shows no gradients at -39 C
- No gradients to few mK level at other temps.

CORSAIR Temp Sensor Uncertainties

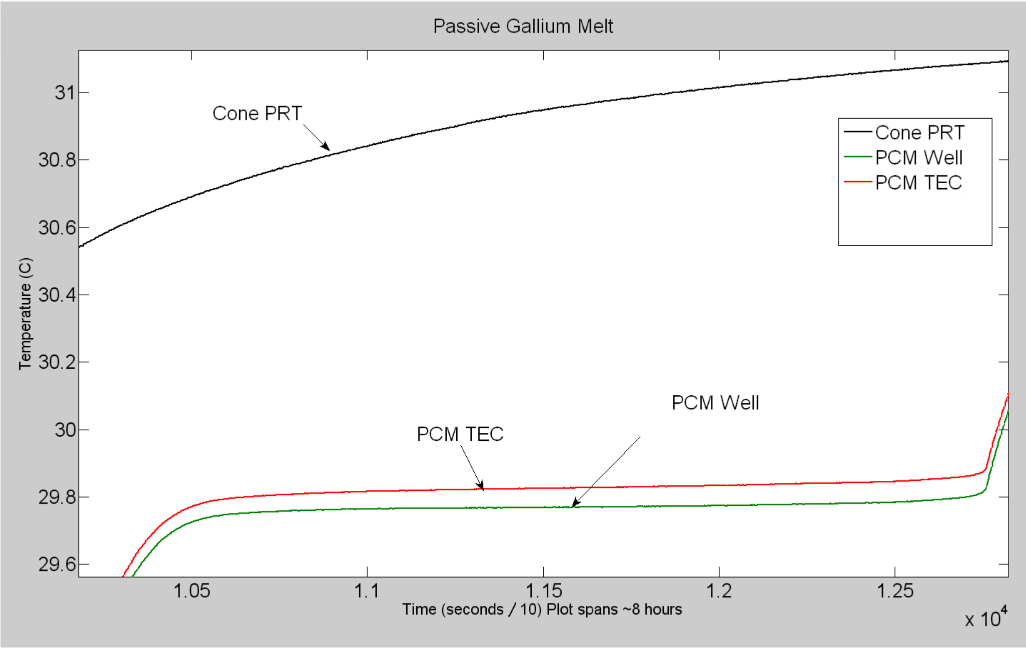
- Blackbody temperature sensors can be calibrated to 10 mK or better. Need to ensure sensors maintain calibration
  - Can drift over time
  - Can change reading from mounting or handling (mechanical stress)

1. In CORSAIR blackbody, multiple sensors agree when in blackbody so calibration is unlikely to have changed
2. CORSAIR blackbody contains phase change cells
   - Cell with water, gallium, and mercury
   - Cell is independently temperature-controlled from blackbody
   - Intended for maintaining calibration of temperature sensors:
     - Take cell through melt point
     - Calibrate sensor in cell
     - Turn off cell, it equilibrates with blackbody
     - Transfer calibration to blackbody sensors



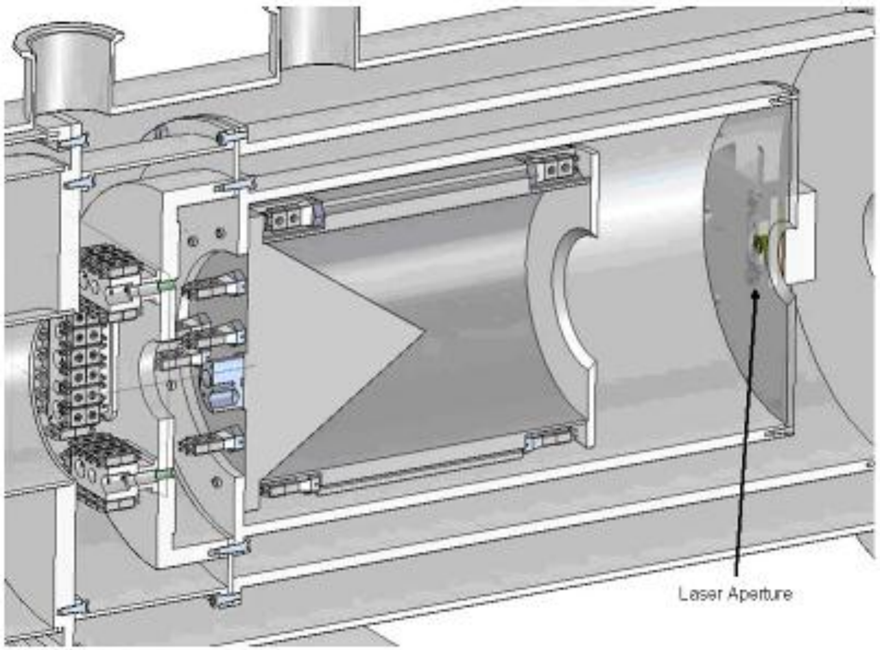
CORSAIR Temp Sensor Uncertainties

- Can identify melt point by going through melt point and observing melt curve
  - Works well for trending
  - Absolute accuracy less clear: melt curve is never completely flat, melting requires some gradient across cell
- Current cell design monitors material expansion to unambiguously identify melt point
  - Take cell to melt point and hold to provide absolute standard
  - Early results show CORSAIR cell temperature sensors consistent with known melt points to within ~20 mK. Temperature sensors were calibrated to ~15 mK (1σ) prior to placement in blackbody



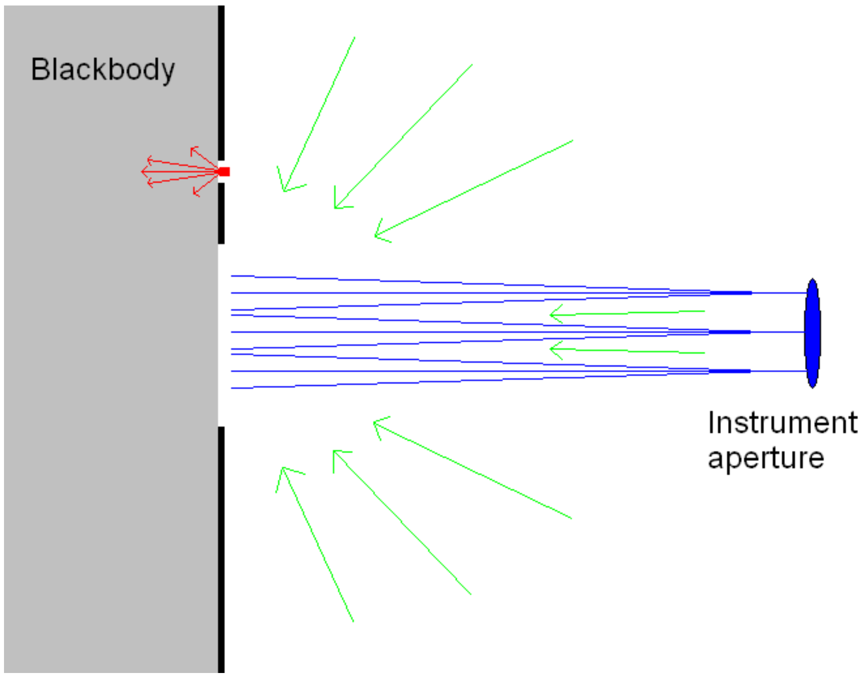
CORSAIR Emissivity

- Emissivity must be high or at least well-known for a blackbody to be considered accurate
- The CORSAIR blackbody includes an emissivity monitor based on a quantum cascade laser (QCL)
  - CLARREO will require emissivity monitor, CORSAIR includes one for demonstration
- Single 9.6 μm 150 mW QCL
- Instrument viewing blackbody is detector
- Broad-beam laser shines into blackbody with no optics



CORSAIR Emissivity

- Simple monitor design mimics observation geometry, so it allows a measure of blackbody emissivity
- Monitor used during test
  - Spectrometer did not detect laser
  - Emissivity ≥0.999,992
  - This is consistent with model and paint data at 9.6 μm



Further Blackbody Testing

- Complete end-to-end testing of blackbodies highly desirable…
  - Earth-observing mission, such as CLARREO, attempting to contribute to a long record of observation need documented SI traceability
  - Historically, when equipment or experimental results have been compared, they are often found to disagree by more then the claimed uncertainties
- …but complicated. Options include
  - Comparison with other blackbodies (using transfer radiometer)
  - Emissivity testing (e.g. CHILR at NIST)
  - Observe with absolute radiometer based on electrical substitution standard
- Sensitivity not yet at level desired for CLARREO
  - Suggest future work on improved testing ability

Summary

- FIRST is a working far-IR spectrometer
- Far-IR blackbodies exist to meet the FIRST accuracy goal
- Prototype far-IR CLARREO blackbody built and appears to meet requirements